

# **HIGH TEMPERATURE ELECTRONICS, COMMUNICATIONS, AND SUPPORTING TECHNOLOGIES FOR VENUS MISSIONS**

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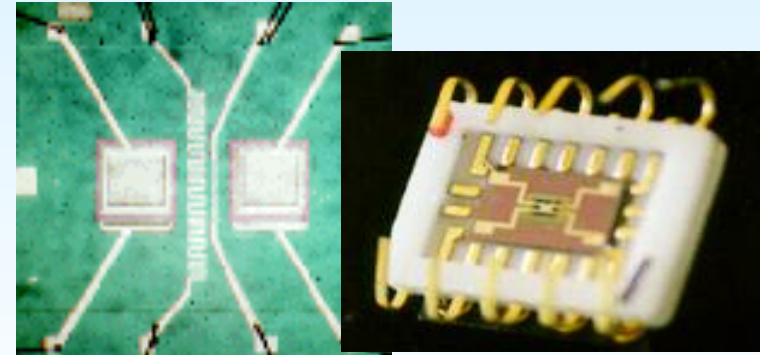
**OAI  
22800 Cedar Point Road  
Cleveland, OH 44142**

# SENSORS AND ELECTRONICS TECHNOLOGY BRANCH

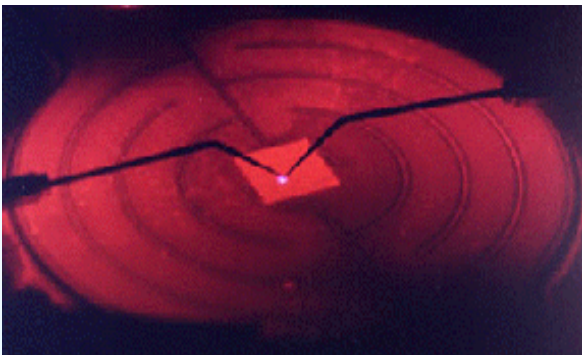
## SCOPE OF WORK



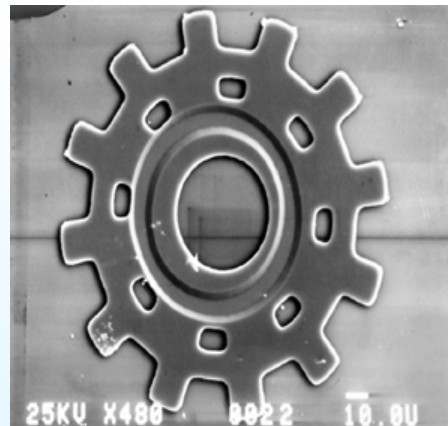
**PHYSICAL SENSORS (T, Strain, Heat Flux)**



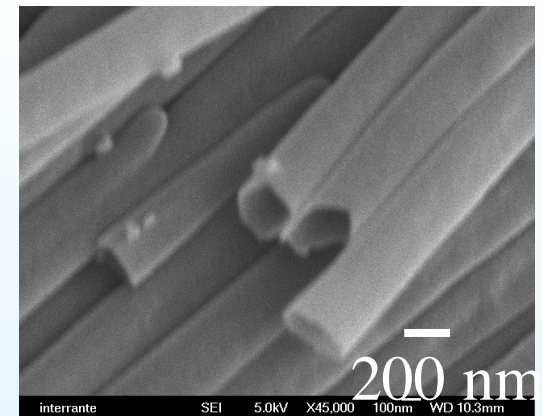
**CHEMICAL SENSORS**



**SILICON CARBIDE HIGH  
TEMP ELECTRONICS**



**MICRO-ELECTRO-  
MECHANICAL SYSTEMS**



**NANOTECHNOLOGY**

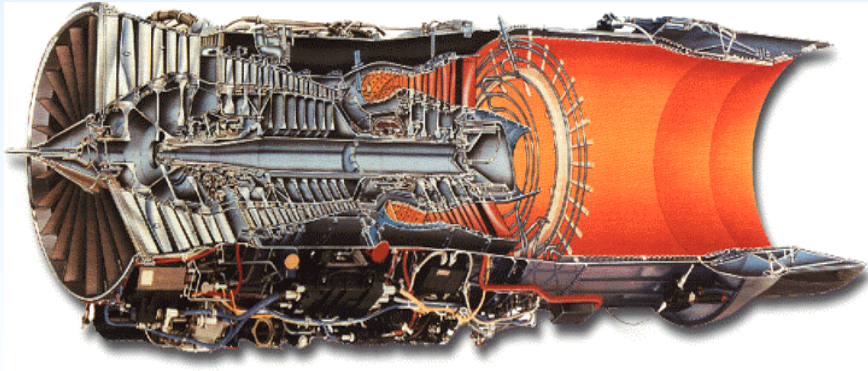
# NASA GRC: CUTTING EDGE DEVELOPMENT HARSH ENVIRONMENT SENSORS AND ELECTRONICS





# HIGH TEMPERATURE ELECTRONICS AND SENSORS BENEFITS TO NASA MISSIONS

Intelligent Propulsion Systems



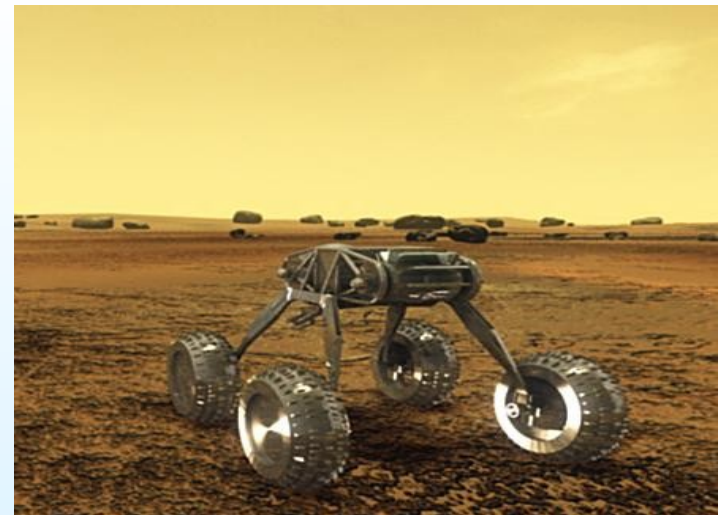
Space Exploration Vision PMAD



More Electric + Distributed Control Aircraft



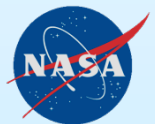
Venus Exploration





# **HARSH ENVIRONMENT VENUS MISSION REQUIREMENTS**

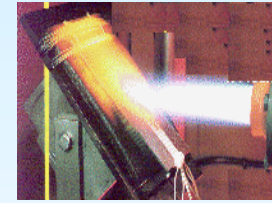
- **SURFACE CONDITIONS**
  - **TEMPERATURE: 450-500 C**
  - **PRESSURE: 90 bar PREDOMINATELY (~100 TIMES EARTH)**
  - **SULFURIC ACID PARTICLES IN CLOUD DECK**
  - **96.5% CO<sub>2</sub> and 3.5% N<sub>2</sub>; Trace Gases include H<sub>2</sub>O, SO<sub>2</sub>, CO, HCL, H<sub>2</sub>, and HF**
- **SOME PARAMETERS OF INTEREST: TEMPERATURE, PRESSURE, CHEMICAL SPECIES, FLOW (WIND)**
- **TEMPERATURE CONTROL INCREASES SYSTEM COMPLEXITY/RISK TO MISSION**
- **NEED TO SHIELD SYSTEM FROM EXTREME ENVIRONMENTS YIELDS INCREASE IN SIZE AND WEIGHT**
- **LIMITED INFORMATION AVAILABLE FROM IN-SITU SYSTEMS DUE TO HARSH ENVIRONMENTS INVOLVED**
- **SCIENTIFIC COMMUNITY: LACK OF VIABLE HARSH SENSOR SYSTEMS SENSORS AND ELECTRONICS FOR IN-SITU CHARACTERIZATION**
- **IN SOME AREAS, NASA GRC HAS ALREADY TECHNOLOGY SOLUTIONS ISSUES NEEDED BY SMD FOR HARSH ENVIRONMENT APPLICATIONS**



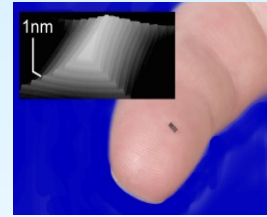
# HARSH ENVIRONMENT ELECTRONICS AND SENSORS APPLICATIONS

- **NEEDS:**

- OPERATION IN HARSH ENVIRONMENTS
- RANGE OF PHYSICAL AND CHEMICAL MEASUREMENTS
- INCREASE DURABILITY, DECREASE THERMAL SHIELDING, IMPROVE IN-SITU OPERATION



1998 R&D 100 Award



2004 R&D 100 Award

- **RESPONSE: UNIQUE RANGE OF HARSH ENVIRONMENT TECHNOLOGY AND CAPABILITIES**

- STANDARD 500C OPERATION BY MULTIPLE SYSTEMS
- TEMPERATURE, PRESSURE, CHEMICAL SPECIES, WIND AVAILABLE
- HIGH TEMPERATURE ELECTRONICS TO MAKE SMART SYSTEMS



1995 R&D 100 Award

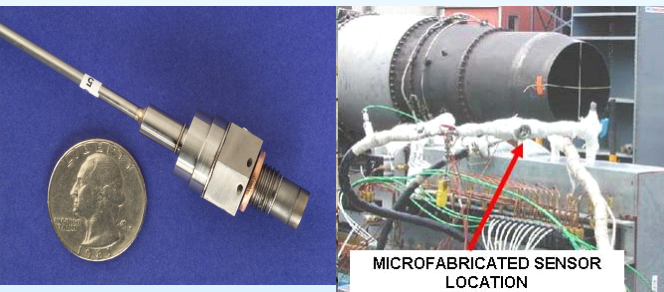


1991 R&D 100 Award

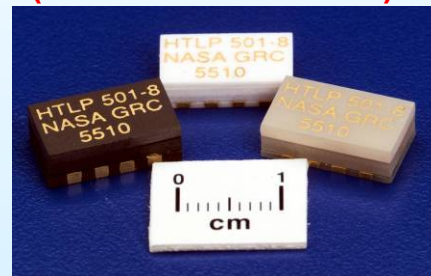
- **ALL-IN-ONE SHOP FOR HARSH ENVIRONMENT SYSTEM APPLICATIONS**

- **ENABLE EXPANDED MISSION PARAMETERS/IN-SITU MEASUREMENTS**

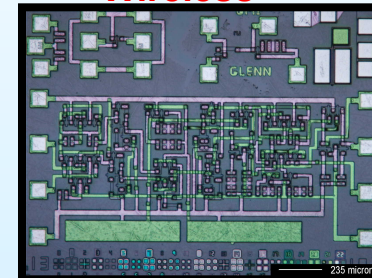
**Range of Physical and Chemical Sensors for Harsh Environments**



**Harsh Environment Packaging  
(2000 hours at 500C)**



**High Temperature Signal Processing and Wireless**

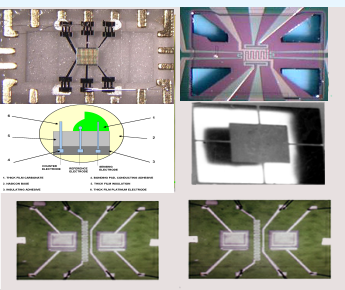


**Long Term: High Temperature "Lick and Stick" Systems**

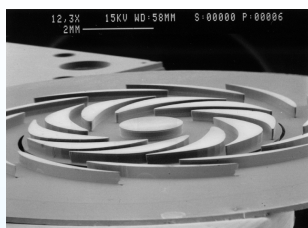


# VENUS SCIENTIFIC MISSIONS LIMITED BY AVAILABILITY OF HARSH ENVIRONMENT SENSORS AND ELECTRONICS

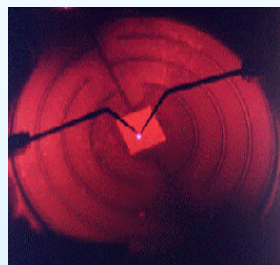
**NASA GRC HAS VAST RANGE OF HIGH TEMPERATURE EXPERIENCE AND IS IN A POSITION TO PROVIDE NEEDED SOLUTIONS**



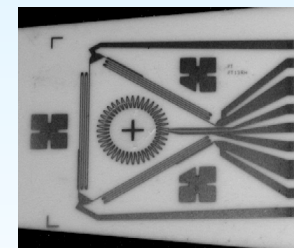
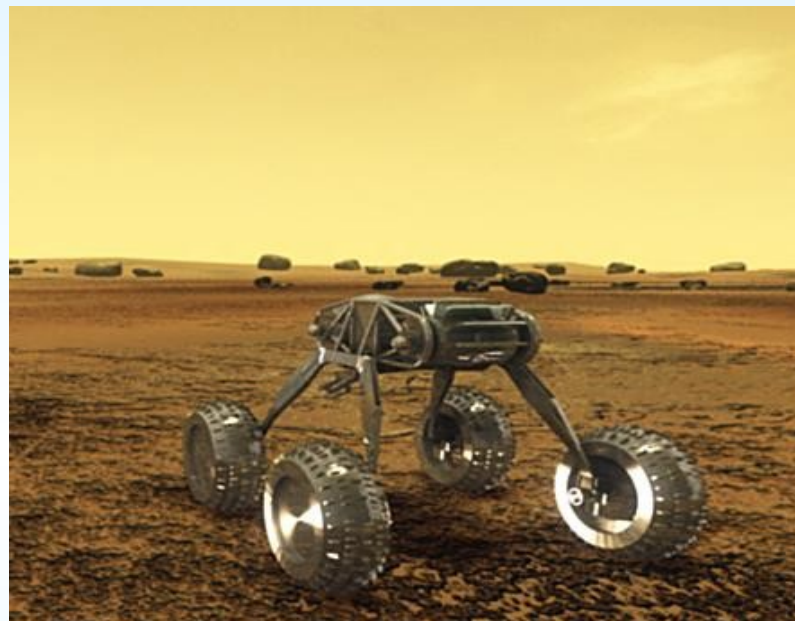
**HIGH TEMPERATURE  
ELECTRONIC NOSE**



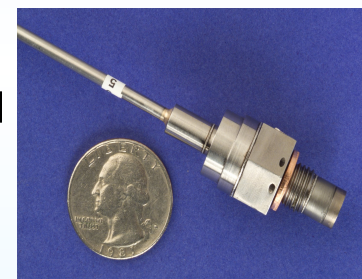
**MICROENGINE,  
ACTUATORS,  
AND FUEL  
DELIVERY**



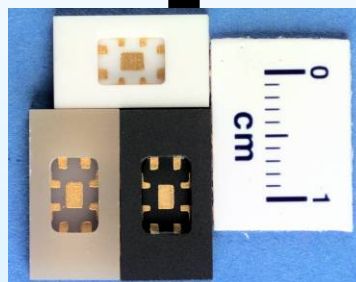
**HIGH TEMPERATURE  
MICROELECTRONICS**



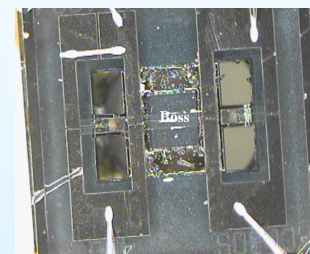
**MULTIFUNCTIONAL  
PHYSICAL SENSOR  
ARRAY**



**600°C PRESSURE SENSOR**



**HIGH TEMP  
PACKAGING**

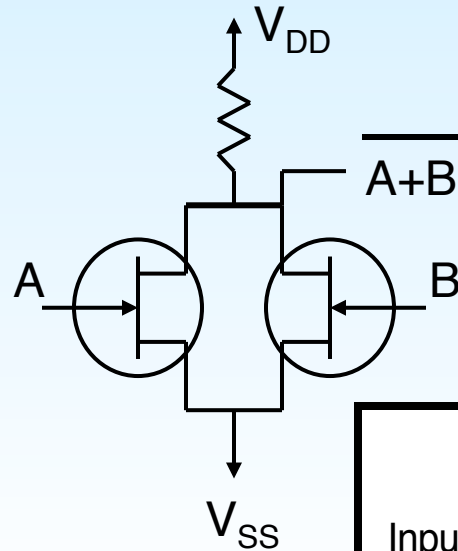
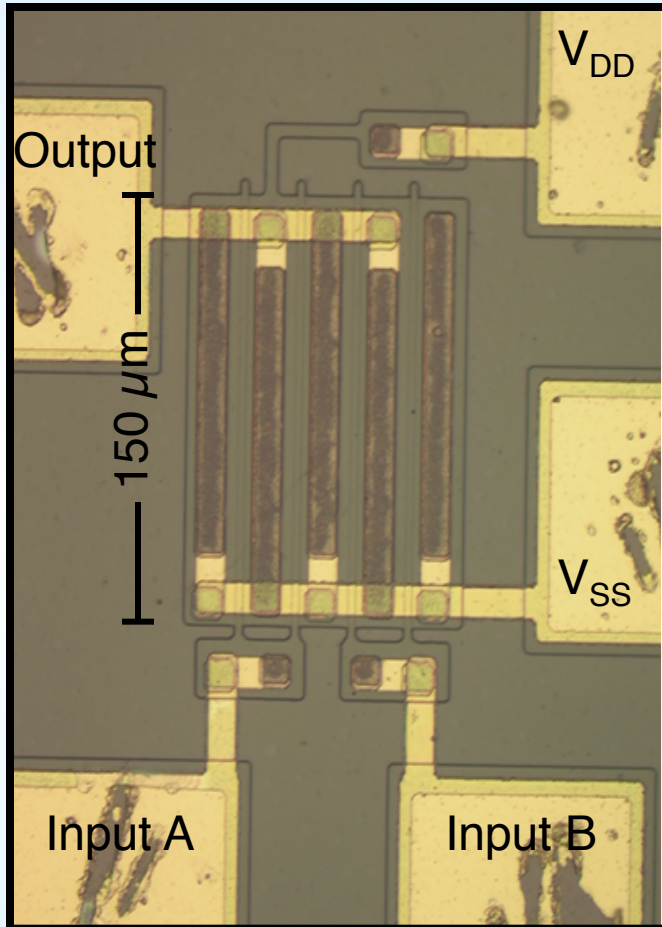


**Hi-g SiC  
ACCELEROMETER**



# 6H-SiC JFET NOR Gate

3 x 300  $\mu\text{m}$  JFET's



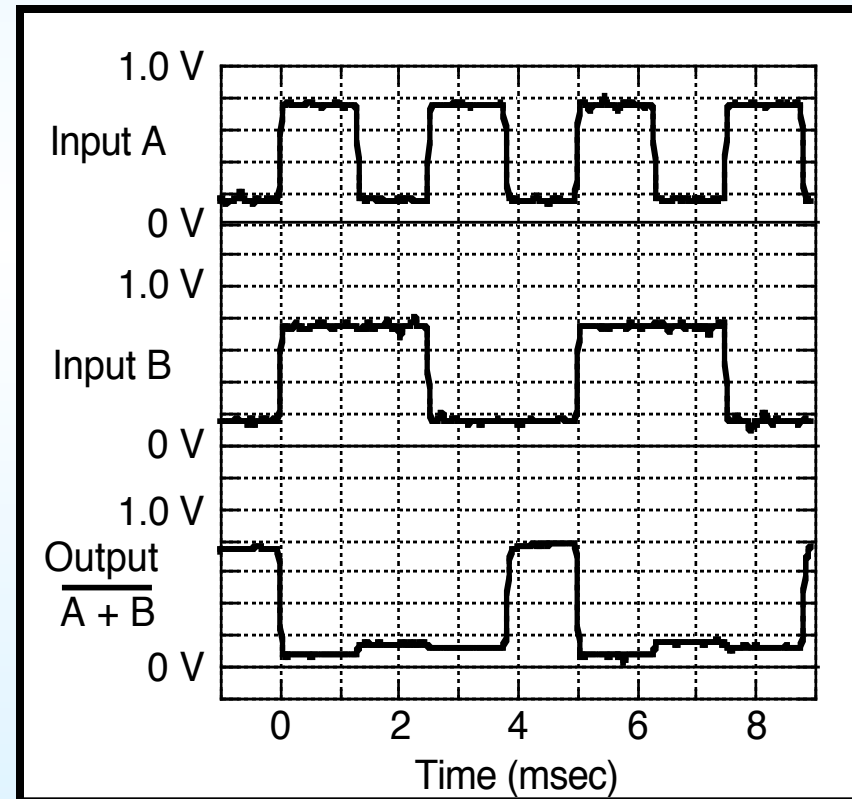
A	B	$\overline{A+B}$
0	0	1
0	1	0
1	0	0
1	1	0

**$T = 600\text{ }^{\circ}\text{C}$**

$V_{DD} = 3.5\text{ V}$

$V_{SS} = 0\text{ V}$

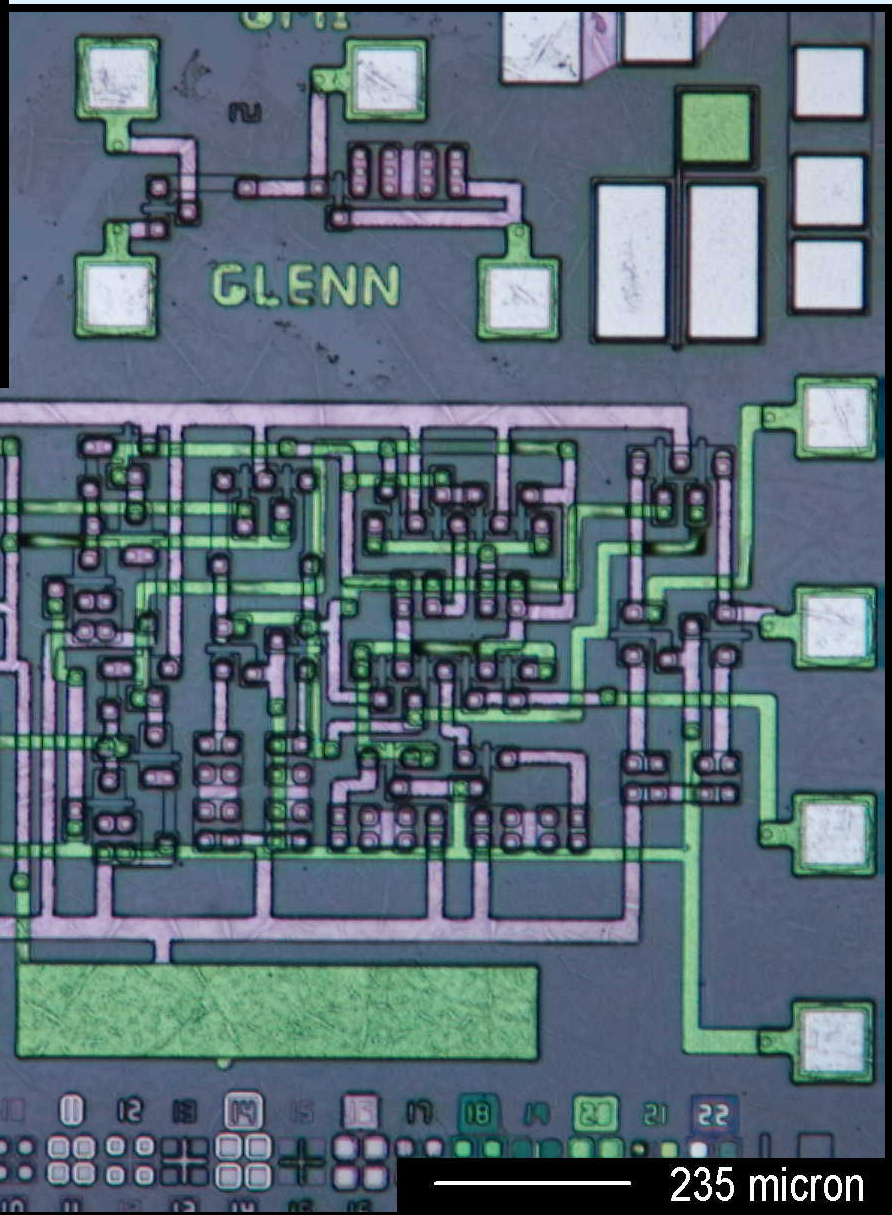
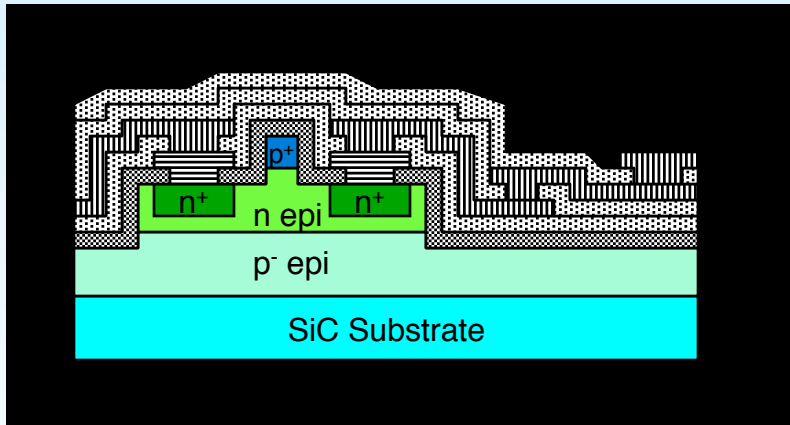
$V_{\text{substrate}} = -1.8\text{ V}$ .



Unpackaged device tested for approx. 1 hour on prober with hot-chuck in 1997.

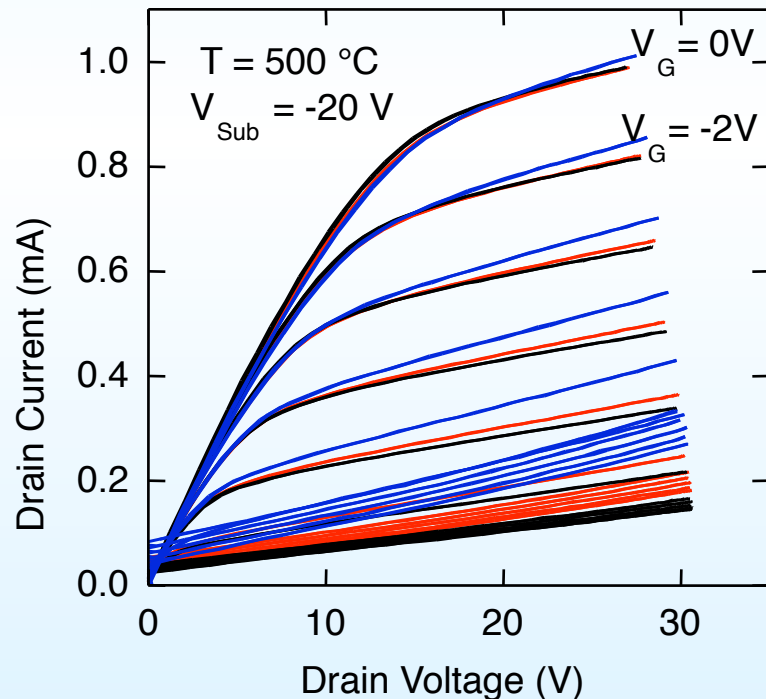
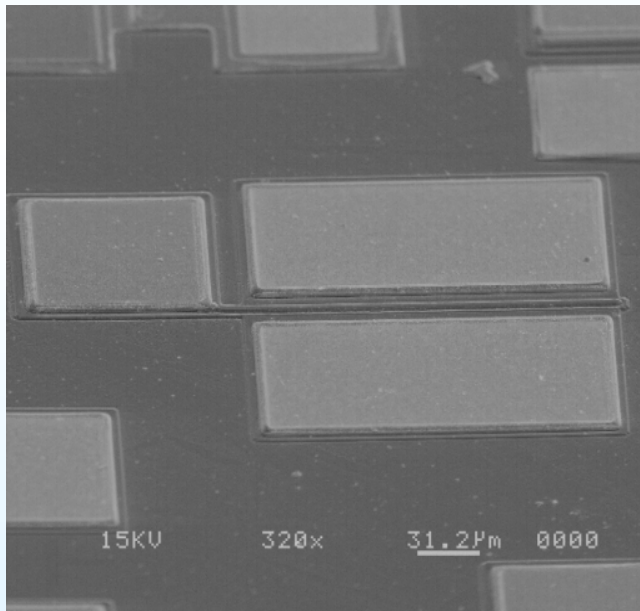
# NASA/GMI 6H-SiC JFET Amplifier Circuit

(Under Construction)



# WORLD' S FIRST 500 °C TRANSISTOR WITH VERY STABLE OPERATION

- 2000 hours of transistor operation achieved (some limited degradation)
- Device Operation Also Demonstrates Viability of Supporting Technologies
  - Packaging and ohmic contacts operated over 2000 hours at 500 °C without degradation.
- Strong Foundation for Improved Device Operation
  - Revised “junction gate” process should enable 2000 hours at 500 °C without transistor degradation.



— Initial Characteristics at 500 °C  
— After 126 h 500 °C  
— After 558 h 500 °C

## WORLD' S FIRST 500 C STABLE TRANSISTOR AND ITS PERFORMANCE OVER TIME



# High Temperature Wireless Development

## OBJECTIVES:

- HIGH TEMPERATURE WIRELESS TELEMETRY, DISTRIBUTED ELECTRONICS OVER A BROAD OPERATING RANGE

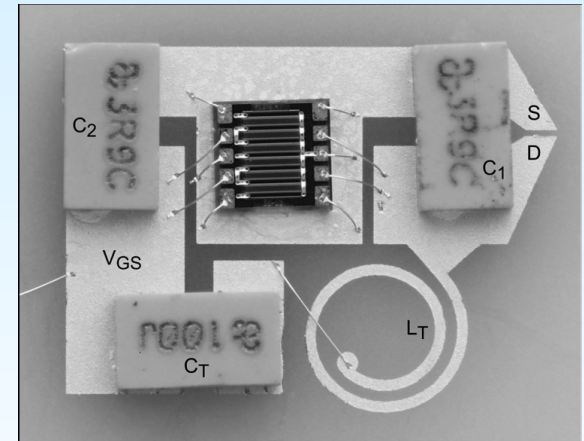
## TECHNICAL CHALLENGES:

- DEVELOPMENT OF RELIABLE HIGH TEMPERATURE TELEMETRY ELECTRONICS, POWER SOURCES, REMOTE COMMUNICATION ELECTRONICS, AND PACKAGING

## GOALS SUPPORTED:

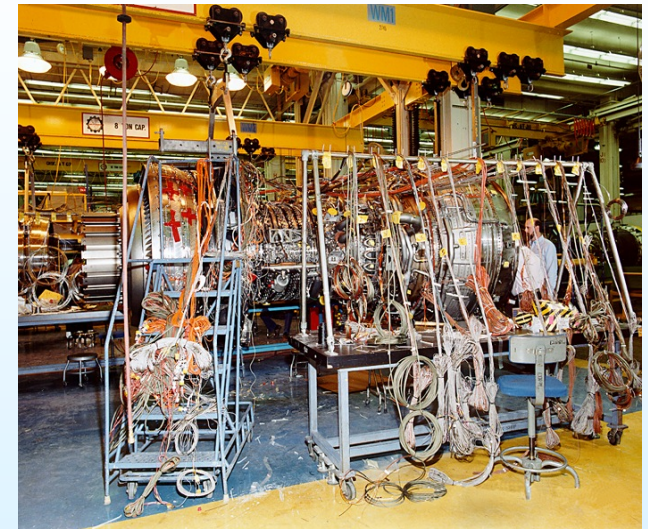
- ENHANCE PERFORMANCE
- SIGNIFICANTLY REDUCE COST

**PROVIDE DATA TRANSFER IN HARSH ENVIRONMENTS IMPROVING RELIABILITY AND ENABLING NEW CAPABILITIES**



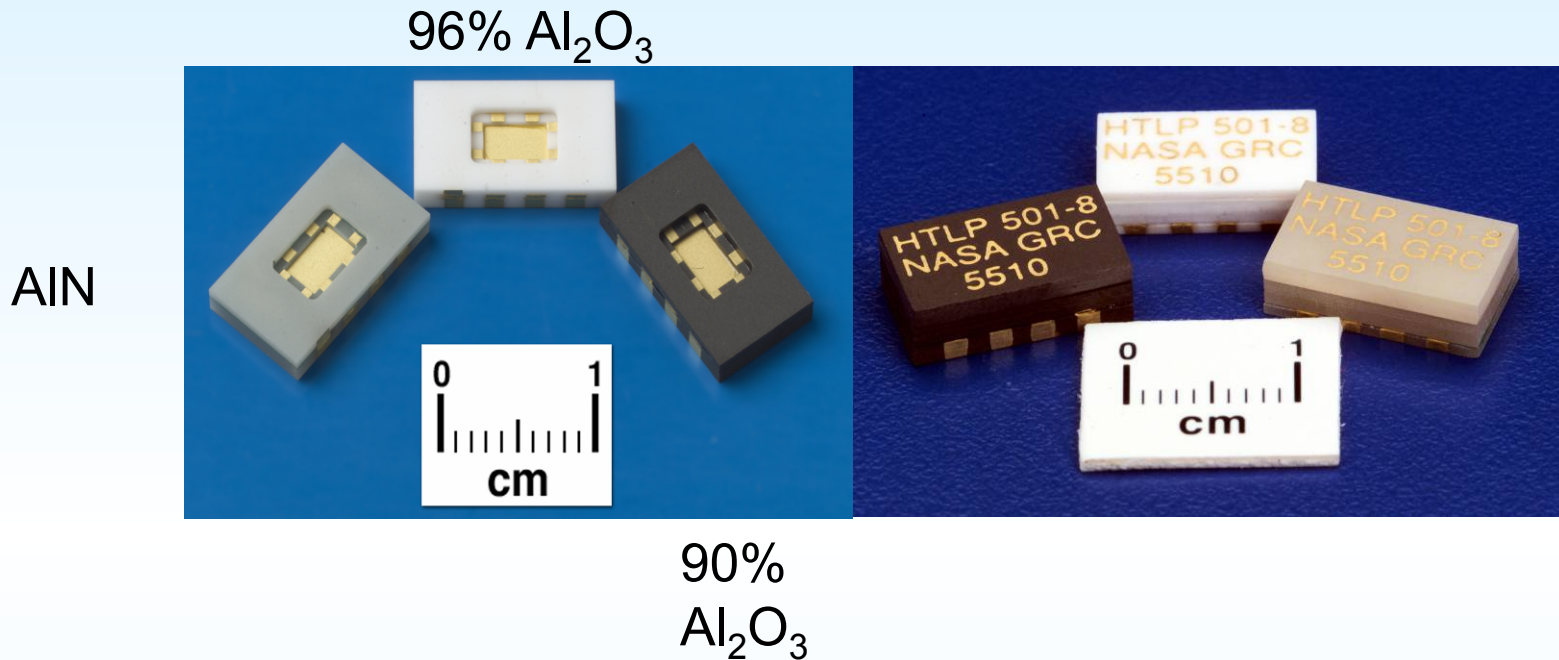
Prototype Oscillator Circuit

**Example: Gas Turbine Engine Development Requires Extensive Instrumentation Yielding Extensive Wiring Complexity**



Wires from 1000 Sensors

# Chip Level Packages for 500°C Application

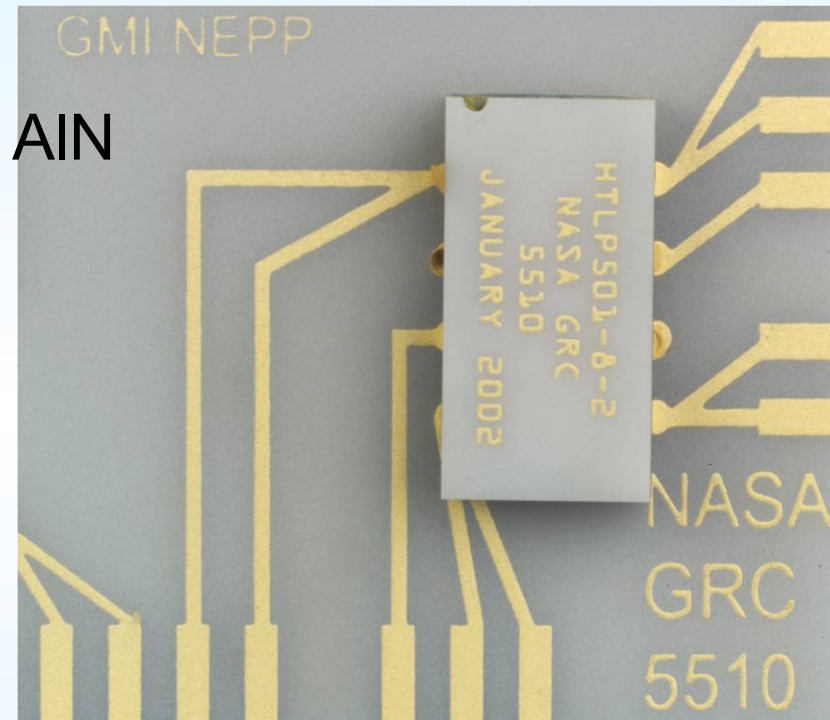


- Three types of ceramic substrate and Au thick-film metallization based chip-level packages
- A compatible low resistance die-attach scheme tested for 1000hrs
- Compatible printed circuit board level interconnection system developed

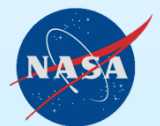
# Circuit Board Level Interconnection



## Electronic Package for High Temperature Micro-Systems



- Three types of ceramic substrate and Au thick-film metallization based PCB
- Interconnection between chip-level packages and PCB
- 500 C technology

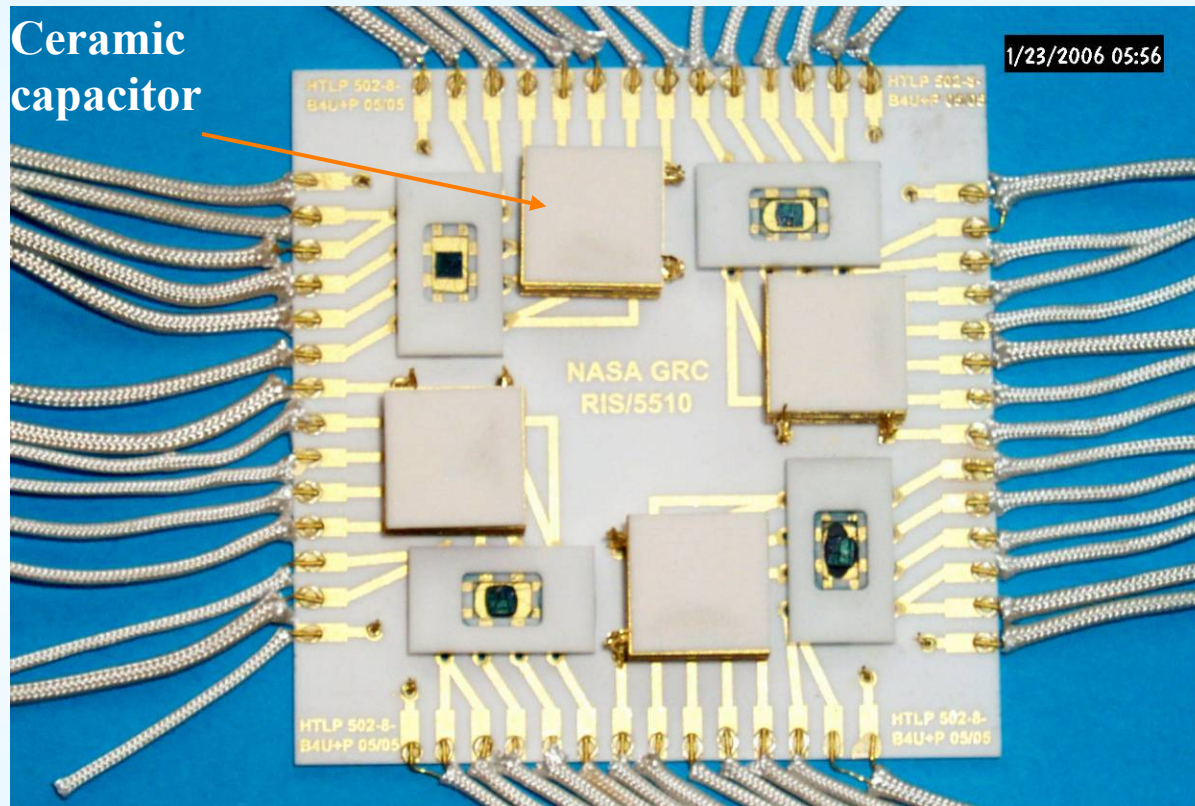




# Demonstration of 500°C AC Amplifier Based on SiC MESFET and Ceramic Packaging – Test assembly 2006



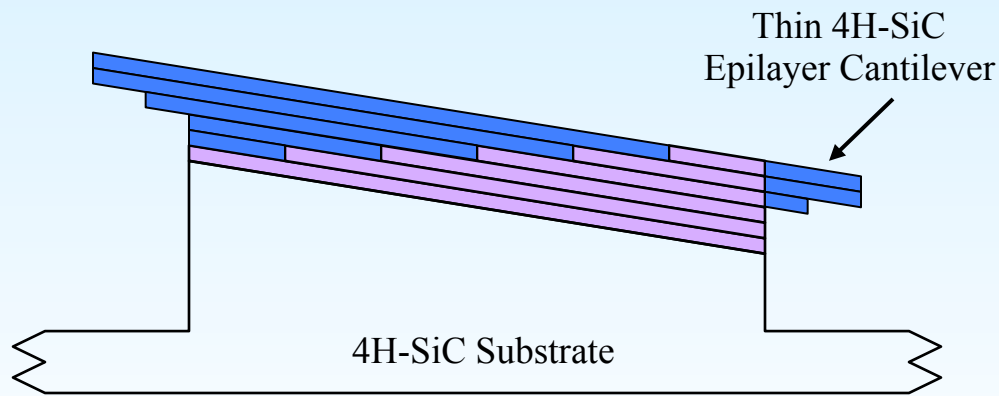
## Optical Picture of the Test Assembly



- The test assembly includes four testing circuit units
- Common - Source AC amplifier tested at 500 C for over 1100 hours

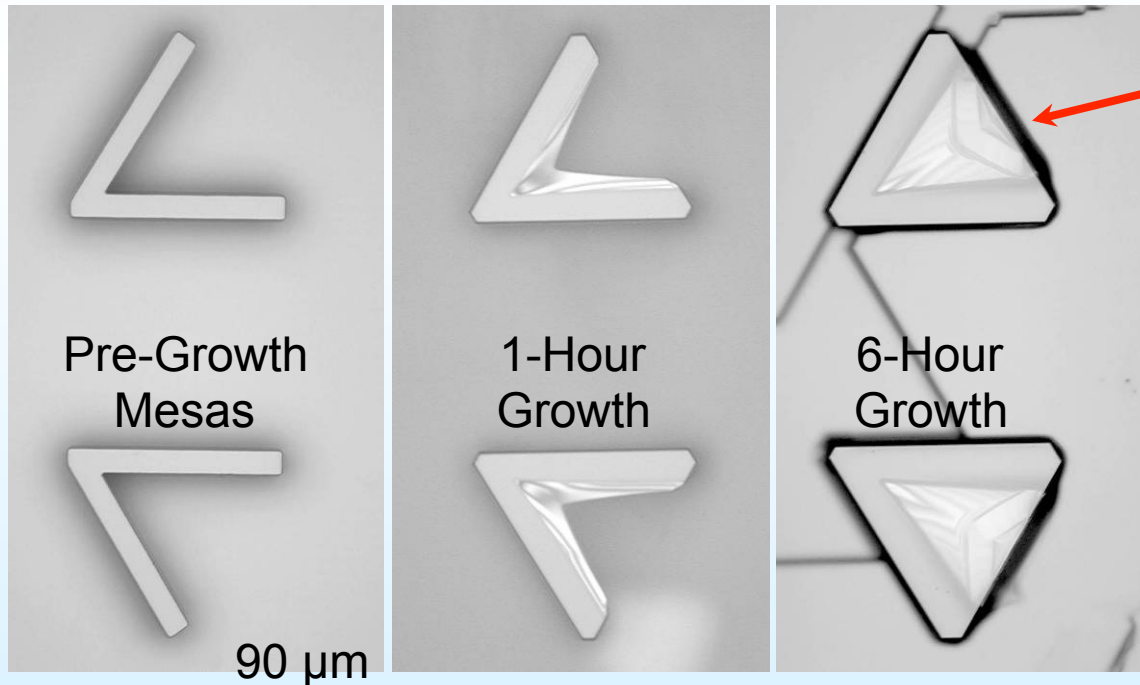
# Atomically Flat SiC Mesas and Cantilevers

P. G. Neudeck et al., J. Appl. Phys. 92 p. 2391 (2002).

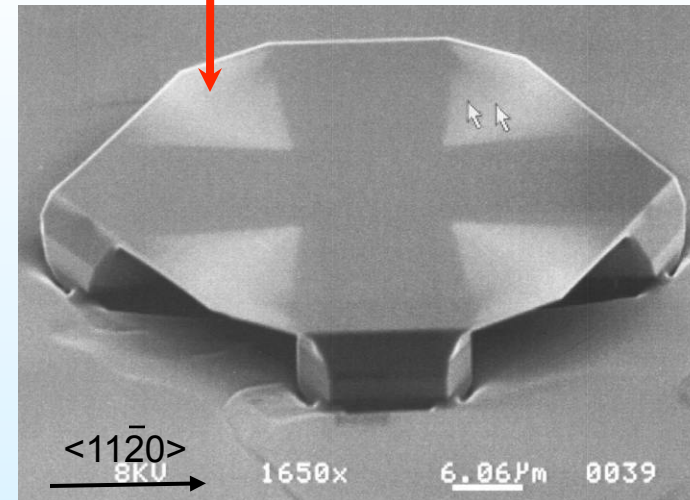


Top surface of mesa is atomically smooth  
completely free of steps.  
Surface can be enlarged by growing defect-free cantilevers.

Defect-free areas large enough for prototype devices!



Atomically Flat  
“Webbed Cantilevers”

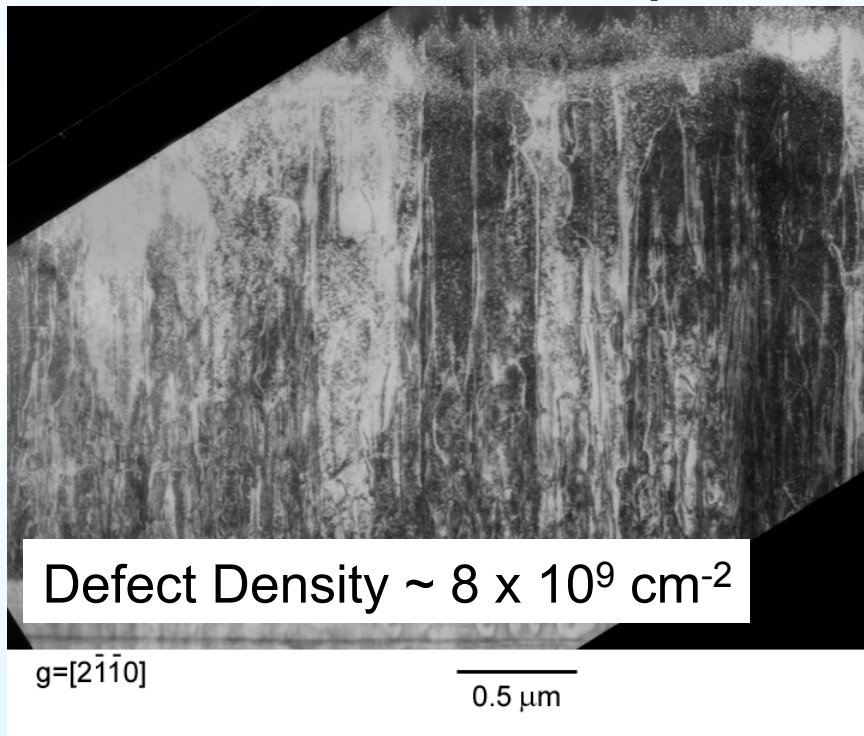


# Accomplishment: Growth of Improved GaN on SiC Films

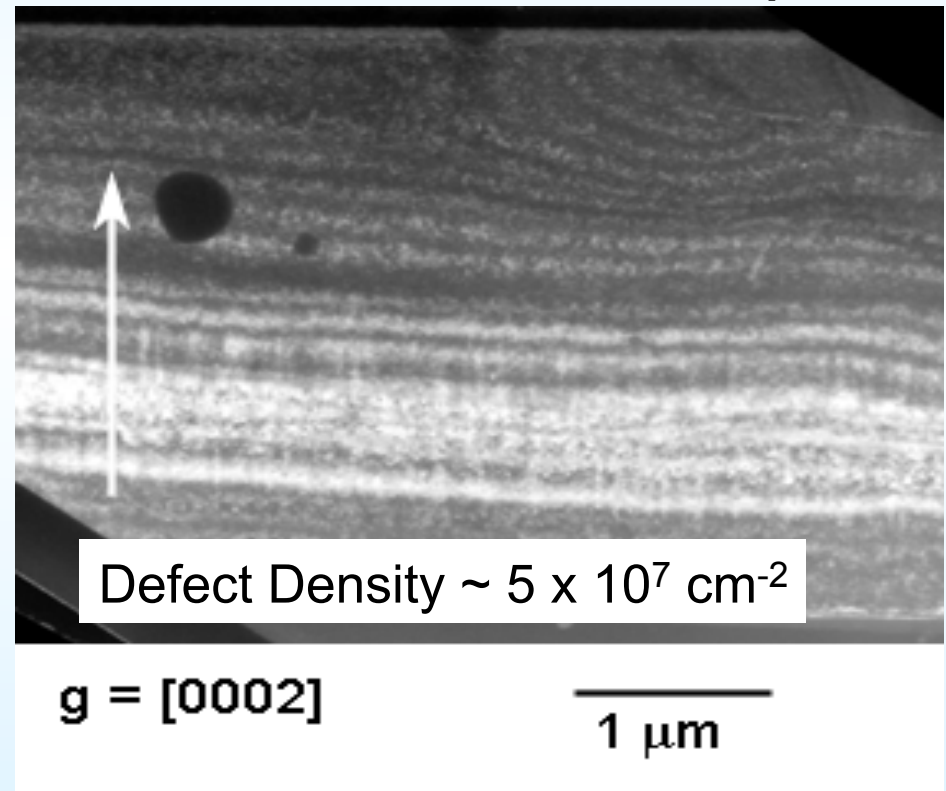
Method: Growth of GaN (by US Naval Research Laboratory) on top of Atomically Flat SiC Mesa Arrays Grown by NASA GRC.

## Transmission Electron Micrographs (from NRL) Comparing GaN on SiC Films

**GaN grown on top of conventional SiC with surface steps**



**GaN grown on top of NASA GRC SiC mesa free of surface steps**



**GaN Dislocation Density Reduced by 100X!**

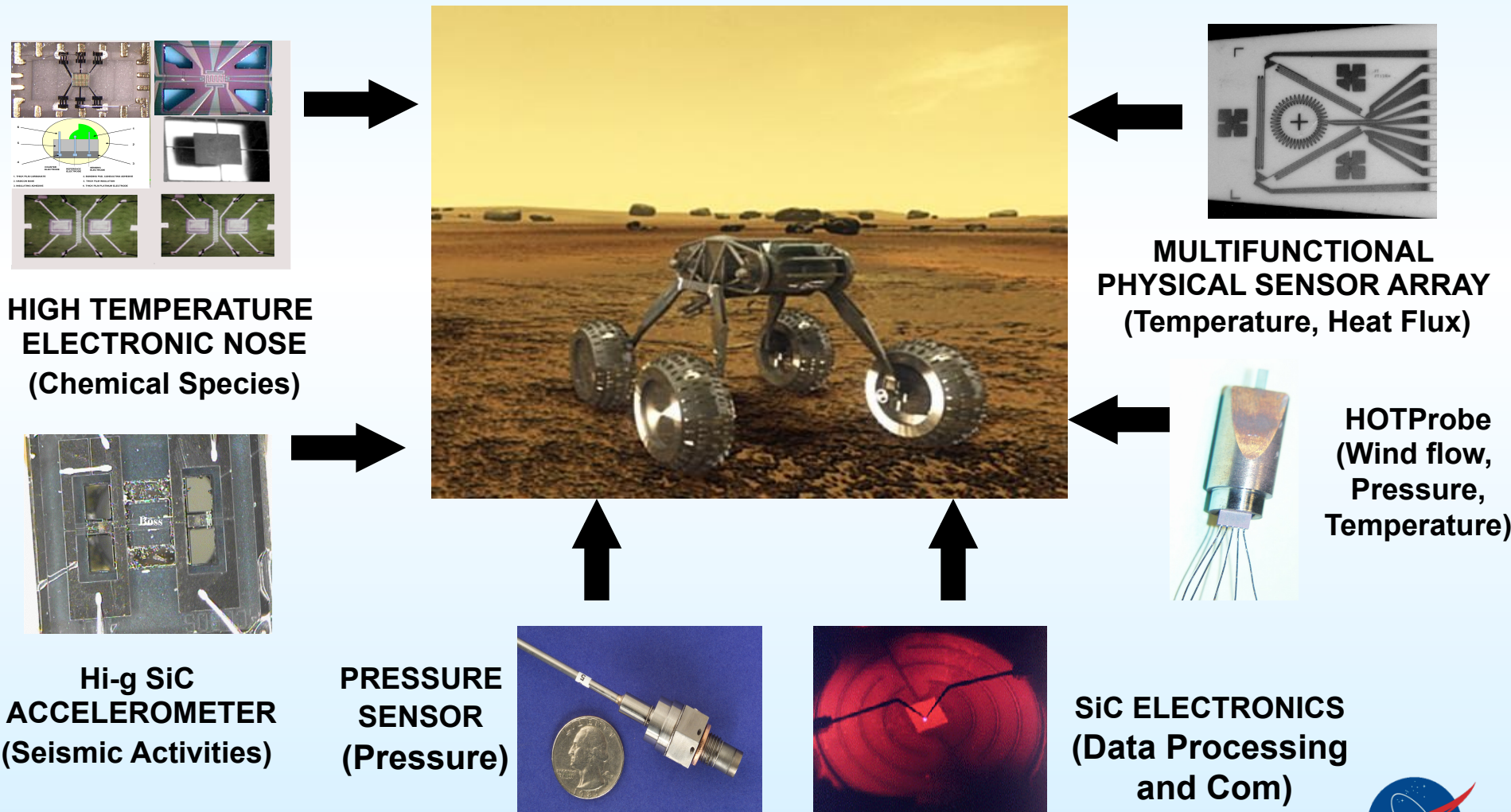


# SUMMARY

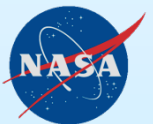
## NASA GRC HAS THE TOOLS TO ENABLE NEW MISSIONS

### EXAMPLE POSSIBLE MISSION: Venus Integrated Weather Sensor (VIWS) System

Sensor Suite to Monitor Venus Weather Conditions including: **Data Processing and Communication, Wind Flow, Seismic, Pressure/Temperature/Heat Flux, Chemical Environment**



# BACK UP SLIDES



# NASA Glenn Microsystem Development Facilities

- Significant In-House Capabilities for a Range of Micro/Nano Sensor and Electronics Development
- Capabilities Range From Semiconductor Material and Device Fabrication to Packaging and Testing
- State-Of-The-Art Facilities Leading to World Leading Technologies

## SiC Chemical Vapor Deposition (CVD) Epitaxial Growth Laboratory



**World's Most up-to-date Facility of Its Type**

## Microsystems Fabrication Clean Room



**3000 Square Foot Clean Room Space for Electronic-Grade Oxides and MEMS**

## Microdevices Characterization Facilities



**A Range of Characterization and Testing Equipment For Device Development**



# **SIC-BASED PRESSURE SENSORS**

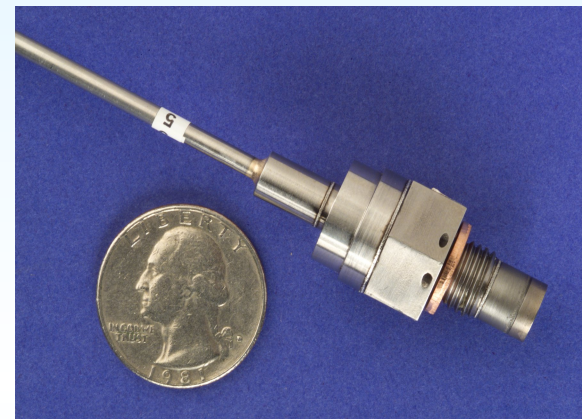
- **SIC HAS EXCELLENT MECHANICAL PROPERTIES FOR USE AS A HARSH ENVIRONMENT PRESSURE SENSOR (T > 500 °C, SILICON UNDERGOES PLASTIC DEFORMATION)**
- **FORM DIAPHRAM OF SIC AND INTEGRATE WITH ELECTRONICS**
- **WIDE RANGE OF APPLICATIONS**

**AERONAUTIC ENGINE APPLICATIONS**

**AUTOMOTIVE APPLICATIONS**

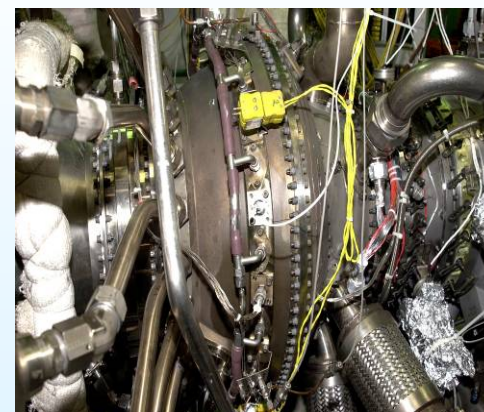
**MATERIAL PROCESSING**

- **ENGINE OPERATION DEMONSTRATED AT 500 C**
- **CAN BE INTEGRATED WITH FLOW VELOCITY AND TEMPERATURE FOR A VENUS HIGH TEMPERATURE WEATHER MONITORING DEVICE**



**500 °C SiC pressure sensor**

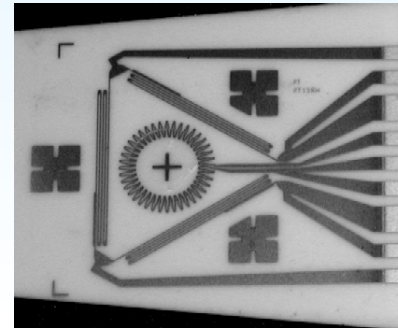
**SiC High Operating Temp. Probe (HOTProbe): SiC chip to simultaneously measure flow velocity, pressure, and temperature;**



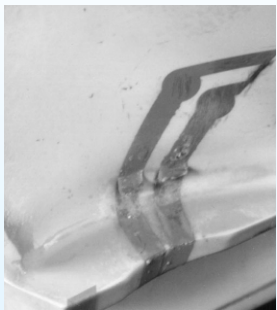
**Real World Application: Pressure Sensor Installed in Engine Test**

# Thin Film Physical Sensors for High Temperature Applications

- **Advantages for temperature, strain, heat flux, flow & pressure measurement:**
  - ♦ Negligible mass & minimally intrusive (microns thick)
  - ♦ Applicable to all materials including ceramic based materials
  - ♦ Minimal structural disturbance
  - ♦ Intimate sensor to substrate contact & accurate placement
  - ♦ Multiple sensor fabrications, full-field measurement
  - ♦ High durability
  - ♦ Capable for operation to very high temperatures ( $> 1000^{\circ}\text{C}$ )
- **Multifunctional smart sensors being developed**
- **Can Be Used To Measure Venus Surface Conditions as well as Monitor Vehicle Conditions**



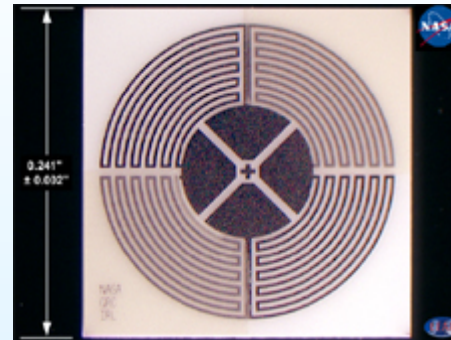
Multifunctional Sensor Array



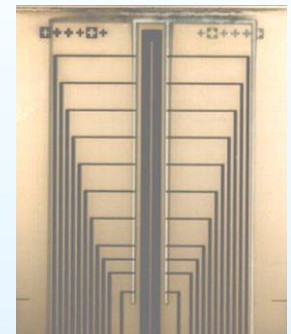
PdCr strain sensor  
On Alloy to  $T=1000^{\circ}\text{C}$



Pt- Pt/Rh temperature  
sensor to  $T=1200^{\circ}\text{C}$



Heat Flux Sensor Array  
to  $T=1000^{\circ}\text{C}$

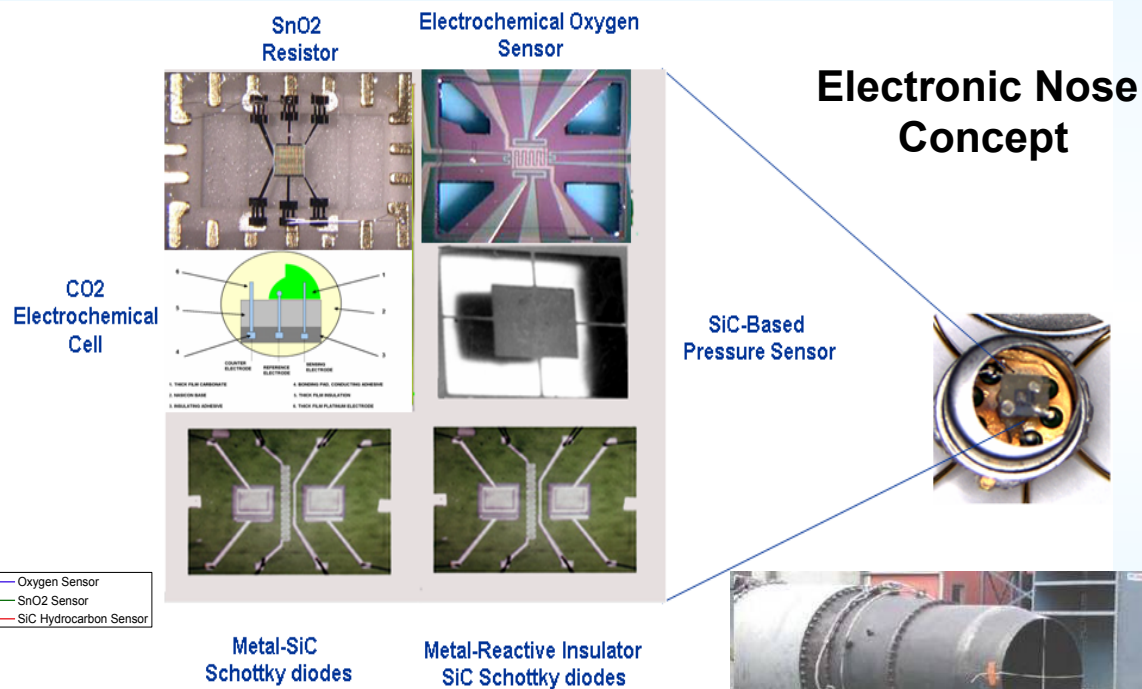
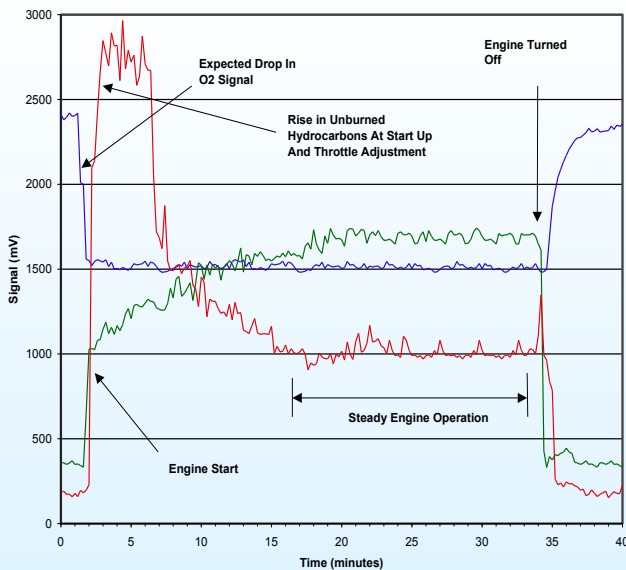


Flow sensor  
to  $T=1000^{\circ}\text{C}$

# HIGH TEMPERATURE GAS SENSOR ARRAY HIGH TEMPERATURE ELECTRONIC NOSE

- High Temperature MEMS Based Gas Sensors Designed for Selective Detection
- Multiple Chemical Species Can Be Measured/Sensors Can Be Tailored for the Application
- Multiple Species of Interest To Venus Applications Can Be Detected

## Automotive Engine Sensor Testing



## Jet Engine Sensor Testing

